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On the Possibility of V4444 Sgr as a Recurrent Nova

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Abstract

V4444 Sgr (Nova Sgr 1999) has been recently suggested to be a possible recurrent nova based on the detection of the preexisting dust, which may have been formed in a previous outburst. We examined this possibility using the available outburst observations, including the VSNET observations. We also noticed that this nova was recorded in the OGLE II public photometric database, which covered both preoutburst and late decline phases. The outburst light curve constructed from these observations showed a plateau phase, particularly in the OGLE II I-band light curve, which was followed by a more rapid decline. The light curve resembled those of "fast" recurrent novae and candidates in the presence of the distinct plateau phase. The outburst spectrum and the preoutburst magnitude more resembled those of classical novae, but they do not exclude the possibility of a recurrent nova.

Key words: astrometry — stars: individual (V4444 Sagittarii) — stars: novae, cataclysmic variables — stars: variable

1. Introduction

Our observational knowledge of recurrent novae has recently made a significant advancement, particularly led by the most recent detections, and prompt announcements through VSNET, of three recurrent nova outbursts: U Sco in 1999 (Schmeer et al. 1999; Munari et al. 1999; Kahabka et al. 1999; Lépine et al. 1999; Anupama, Dewangan 2000; Evans et al. 2001; Iijima 2002), CI Aql in 2000 (Takamizawa et al. 2000; Kiss et al. 2001; Matsumoto et al. 2001; Matsumoto et al. 2003a; Burlak, Esipov 2001), and IM Nor in 2002 (Liller 2002; Kato et al. 2002). Theoretical models have been able to reproduce the observed features of the recurrent novae (Hachisu et al. 2000a, Hachisu et al. 2000b). Even a prediction of supersoft X-ray phase and turnoff has been made (Hachisu, Kato 2001). However, the most recent two recurrent novae, CI Aql and IM Nor, have a significant departure from the classical descriptions of recurrent novae (Webbink et al. 1987a; Webbink et al. 1987b; Anupama 1992), in their classical nova-like light curves and spectra. Kato et al. (2002) even proposed that IM Nor and CI Aql comprise a new subclass of recurrent novae with massive ejecta and long recurrence times, which may be an indication that these objects are transitional objects between classical novae and recurrent novae. In any case, recurrent novae are now recognized to comprise a more heterogeneous population of novae than was previously thought.

V4444 Sgr (Nova Sgr 1999) was discovered by M. Yamamoto (Kushida et al. 1999). The nova nature was confirmed by the presence of strong, broad emission lines (Liller 1999; Garnavich et al. 1999). The nova declined very rapidly, at a rate corresponding to $t_2 \sim 3.5$ d (Kawabata et al. 2000), which qualifies V4444 Sgr to be a very fast nova according to the classification by Payne-Gaposchkin (1957).

Kawabata et al. (2000) reported, from spectropolarimetric observations, that the nova showed intrinsic polarization, whose properties were explained by scattering by surrounding small dust grains. Kawabata et al. (2000) further suggested that these dust grains may have produced by a previous explosion. Venturini et al. (2002) performed near-infrared spectroscopy, and detected thermal emissions which can be attributed to dust. Venturini et al. (2002) discussed, from the lack of a detectable dust-forming episode in the visual light curve, that the dust is likely to be preexisting. From these observations, Venturini et al. (2002) suggested that V4444 Sgr may be a recurrent nova.

We recently noticed that V4444 Sgr was detected as a transient-type variable star (OGLE II BUL-SC19-V1874) during the Optical Gravitational Lensing Experiment II (OGLE II; Udalski et al. 1997) bulge variable star database (Wozniak et al. 2002). Since this observation covered the important stages of the outburst, we reexam-

Table 1. CCD multicolor photometry.

HJD−2450000	B	V	R_c
1298.154	9.83	8.99	8.29
1299.187	9.94	9.21	8.40
1305.166	11.03	—	9.23
1306.153	11.09	10.64	9.24
1307.185	11.32	10.86	9.34
1309.153	11.53:	11.13	9.45
1311.195	11.75	11.31	9.60
1319.144	12.46	11.92	10.04
1330.081	12.78	12.73	10.89
1331.186	—	12.74	—
1342.161	13.89	13.90	11.54
1343.147	13.92	13.69	11.69
1367.197	14.56	14.34	12.62
1369.081	14.82	14.30	12.72
1384.170	14.92	—	12.91
1409.010	—	14.93	13.56
1426.989	—	15.13	14.40

ined the outburst light curve using this archival data, and discuss the possibility of a recurrent nova in view of the recent knowledge of recurrent novae.

2. Observation and Data Analysis

The visual, photographic and CCD data used to construct the overall outburst light curve are from the reports to the VSNET (Kato et al. 2003).

The multicolor CCD observations were made by SK, with a 25-cm Schmidt–Cassegrain telescope and an AP-7 CCD. The magnitudes were determined using the neighboring Tycho stars. The data are listed in table 1.

The newly analyzed data are from the OGLE II variable star public archive.[1] In the OGLE II original data, the nova was below the limit of detection until HJD 2451290.898 (1999 April 21). The OGLE II PSF photometry yielded unsuccessful fitting results on 19 nights between HJD 2451295.682 (1999 April 26) and HJD 2451342.749 (1999 June 13). This period corresponds to a period when the nova was brighter than $V = 13$, which must have caused a saturation on OGLE II images. We used the I-band magnitudes after this period.

3. Astrometry and Pre-outburst Magnitude

Kushida et al. (1999) reported that nothing obvious appears at this location of the nova on the Digital Sky Survey (DSS). We tried to make refined astrometry, in order to obtain a more stringent limit to the pre-outburst magnitude.

Astrometry of the outbursting V4444 Sgr was performed on a CCD image taken by SK (figure 1). A measurement (UCAC1 system, 115 reference stars; fitting error was $\sim 0''.2$) has yielded a position of $18^h07^m36^s.198$, $-27°20'12''.95$ (J2000.0). The published and newly determined positions are summarized in Table 2. Our position basically agrees with the OGLE-II position. The small difference is possibly caused by the difference in the selection of reference catalogs.

Table 2. Astrometry of V4444 Sgr.

Source	R.A.	Decl.
	(J2000.0)	
Kushida et al. (1999)	18 07 36.22	−27 20 13.5
OGLE II catalog	18 07 36.22	−27 20 13.4
This work	18 07 36.198	−27 20 12.95

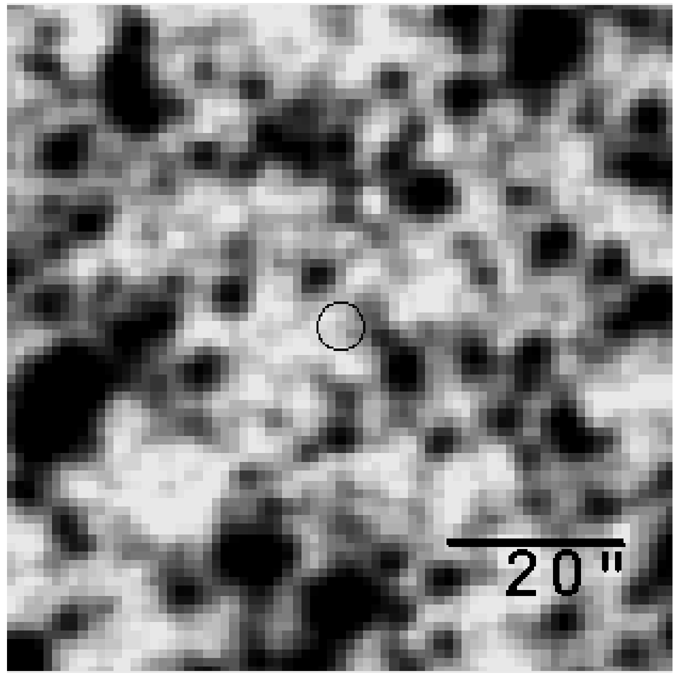

Fig. 2. Enlargement of the DSS 2 red image. The central circle (5 arcseconds in diameter) represents the position of V4444 Sgr.

On DSS 2 red images, a faint object (red magnitude about 19) exists within $0''.6$ of our position (figure 2). This object can be the nova in quiescence, and constrains the lower limit of the outburst amplitude to be 11 mag.

4. Outburst Light Curve

The overall light curve constructed from the reports to VSNET is presented in figure 3. CCD multicolor photometry is shown in figure 4. The light curve seems to be composed of a rapidly fading initial stage and a stage of a more gradual decline.

[1] ⟨ftp://bulge.princeton.edu/ogle/ogle2/bulge_dia_variables/plain_text/BUL_SC19/bul_sc19_1874.dat⟩.

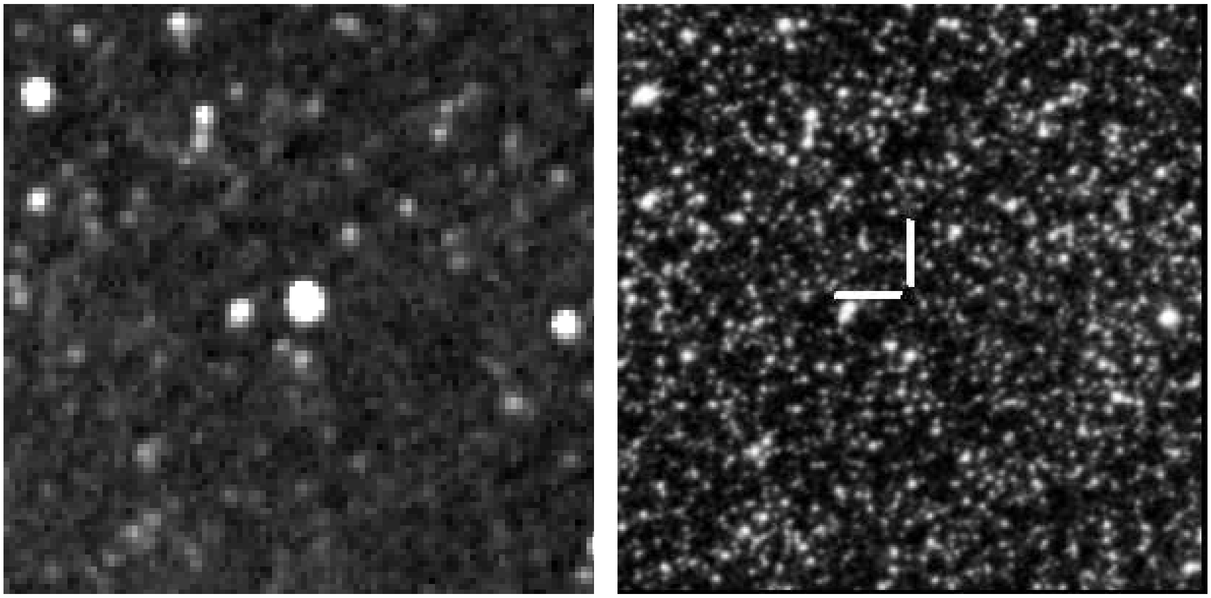

Fig. 1. Identification of V4444 Sgr. North is up, east is left, 5 arcmin square. Left: Outburst image of V4444 Sgr. Right: The quiescent position (tick marks) on the DSS 2 red image. See figure 2 for an enlargement of DSS 2.

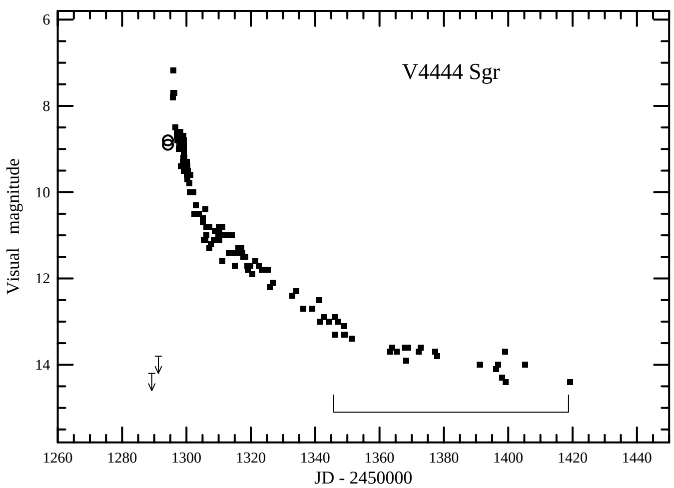

Fig. 3. Overall visual outburst light curve of V4444 Sgr. A V-band maximum observation by Zissel (1999) has been supplemented. The open circles and the arrows are the discovery photographic observations and prediscovery upper limits, respectively. The labeled epoch correspond to the OGLE II I-band light curve in figure 5 (the OGLE II data are not plotted on this figure).

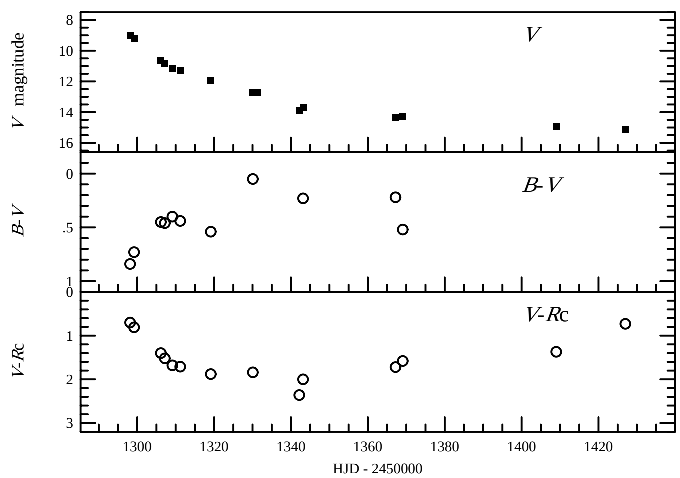

Fig. 4. Multicolor photometry of V4444 Sgr.

5. Pre-outburst Light Curve

Figure 6 shows OGLE II I-band pre-outburst observations. The raw fluxes are shown, which has a large zero-point offset (approximately -10000, not corrected here; the OGLE II unit 1000 approximately corresponds to I = 17.2). There is no indication of a brightening before the outburst. Since the initial detection ($m_{\rm pg}$ = 8.8) by Yamamoto was made on HJD 2451294.235, this observation severely constrains the rise time to be less than 3.3 d. These pre-outburst observations preclude the possibility of a steady rising for $\sim$1000 d in V533 Her and LV Vul (Robinson 1975), or a month-long premaximum rise in V1500 Cyg (Kukarkin, Kholopov 1975).

6. V4444 Sgr as a Recurrent Nova Candidate

We discuss the possibility of a recurrent nova in view of the recent knowledge of recurrent novae.

6.1. Spectroscopic Features

The spectra of V4444 Sgr taken during the outburst (Kawabata et al. 2000) are indistinguishable from those of FeII-class classical novae (Williams 1992), and are unlike those of U Sco (Barlow et al. 1981; Sekiguchi et al. 1988). Such FeII-class spectra have historically been recorded

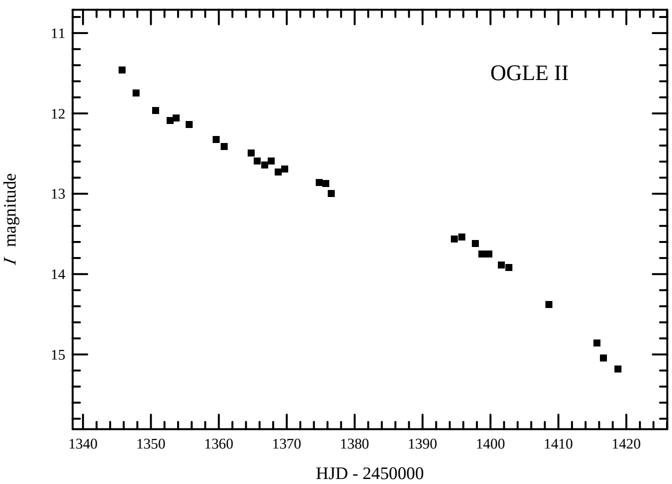

Fig. 5. OGLE II I-band observations. The observed epoch correspond to the slowly declining stage of the outburst. The error bars are smaller than the marks.

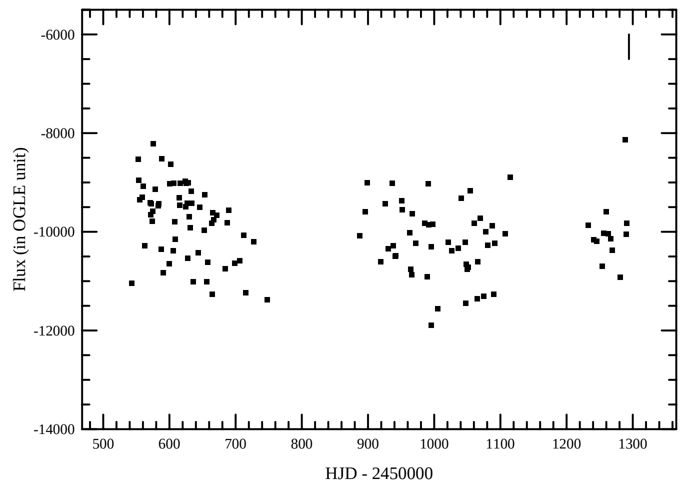

Fig. 6. OGLE II I-band pre-outburst observations. The raw fluxes (in OGLE II unit) are shown, which have a large zero-point offset (not corrected here). There is no indication of a brightening before the outburst. The vertical tick at HJD 2451294.232 corresponds to the epoch of the initial detection by M. Yamamoto.

only in classical novae. The recent discoveries of FeII-class recurrent novae (CI Aql and IM Nor), however, makes this distinction less meaningful than in the past.

6.2. Light Curve

The light curve bears some resemblance to those of recurrent novae. As shown in figure 5, the I-band light curve shows an almost linear decline between JD 2451350 and JD 2451400.[2] This stage with a linear decline seems to corresponds to the *plateau phase*, which is characteristic to recurrent novae (Hachisu et al. 2000a; Hachisu, Kato 2001; Hachisu et al. 2002). During the plateau phase, continuum emission from the accretion disk significantly contributes to the overall light (see Sekiguchi et al. 1988; see also Hachisu et al. 2000a for a theoretical estimate). The relative increase of the contribution from the continuum may explain the decrease of the $V-R_{\rm c}$ color index during this period (cf. figure 4).

The observed duration of the plateau phase ($\sim$ 50 d) is longer than $\sim$16 d of the U Sco outburst in 1999 (Matsumoto et al. 2003b) and $\sim$20 d for the suggested recurrent nova V2487 Oph (Hachisu et al. 2002), but is shorter than $\sim$1.4–1.7 yr of the CI Aql outburst in 2000 (Matsumoto et al. 2003a).[3]

After JD 2451400, the nova started to fade more rapidly, which is consistent with the termination of the plateau phase, rather than a more continuous decrease in the decline rate in most of classical novae (cf. Bode, Evans 1989). The lack of reddening during the fading stage seems to preclude a possibility of a dust-forming episode [see Duerbeck (1981) for representative color changes]. The characteristics of the light curve of V4444 Sgr thus resembles those of "fast" recurrent novae. If V4444 Sgr indeed turns out to be a recurrent nova, V4444 Sgr is expected to have intermediate properties between U Sco and CI Aql.

6.3. Progenitor

As shown in figure 3, the progenitor of V4444 Sgr was about mag 19. If we adopt the maximum M_V of -6.4 ± 0.4 as in the recurrent nova U Sco (Hachisu et al. 2000a; Hachisu et al. 2000b), the preoutburst M_V is estimated to be $\sim+4.5$. This value is a typical prenova magnitude of a classical nova (Warner 1986), but looks slightly faint for a recurrent nova, since recurrent nova outbursts would require a high accretion rate (Hachisu et al. 2000b). If the maximum M_V is -9.0 ± 0.2 (Kawabata et al. 2000) assuming the relation in classical novae (della Valle, Livio 1995), the preoutburst magnitude of $M_V\sim2$ is, alternatively, slightly too bright for a classical nova (Warner 1986).

If V4444 Sgr is indeed a recurrent nova, we may need an obscuration by the previously ejected materials, as has been proposed to explain the faint quiescence of U Sco (Hachisu et al. 2000b). Considering the likely existence of dust before the outburst, this possibility is not surprisingly unlikely. It is also known that the recurrent nova IM Nor has a faint quiescence (Kato et al. 2002), which can be attributed to the short-period and probably eclipsing nature of this system (cf. Woudt, Warner 2003); this possibility would be tested by future observations.

[2] The tendency of the light curve may look slightly different from the visual observation (figure 3). This is probably because of the contamination from emission lines and because of the difficulty in visually measuring the faint object $V\sim14$. Since the I-band is less affected by strong emission lines, the I-band light curve provides the best estimate of the continuum variation.

[3] There was a dip-like fading during the late stage of the 2000 outburst of CI Aql. The duration of the plateau phase before this dip was $\sim$160 d (Matsumoto et al. 2001).

7. Summary

V4444 Sgr (Nova Sgr 1999) has been recently suggested to be a possible recurrent nova based on the detection of the preexisting dust, which may have been formed in a previous outburst. We examined this possibility using the available outburst observations. We have newly identified the nova in the OGLE II bulge variable star database. The OGLE II record covered both preoutburst and late decline phases of this nova. The outburst light curve showed a plateau phase, particularly in the OGLE II I-band light curve, which was followed by a more rapid decline. Quasi-simultaneous optical multicolor photometry precludes the possibility of a dust-forming episode as the origin of this fading. The light curve thus resembled those of "fast" recurrent novae and candidates in the presence of the distinct plateau phase. The outburst spectrum and the preoutburst magnitude more resembled those of classical novae, but they do not exclude the possibility of a recurrent nova. If V4444 Sgr is an indeed a recurrent nova, the relatively faint pre-outburst magnitude would require an obscuration by the preexisting dust prior to the 1999 outburst, or the object may be similar to the short-period, probably eclipsing recurrent nova, IM Nor. We have been able to exclude the possibility of a pre-outburst gradual rise observed in a few past classical novae.

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